AI Program Office

Burt Holzman, for the AI Program Office
(Nhan Tran, Farah Fahim, Tia Miceli, Brian Nord, Gabe Perdue, Tingjun Yang)

Lab-wide AI Meeting

02 Dec 2022

Before we get started …

- Intended to be an open discussion – please (politely) interrupt!
- Nothing is set in stone: we need your input.
- Some ideas presented are aspirational
- AI Program predates COVID: we have tried to be agile and adapt to the changing environment

- Reach out to us: ai@fnal.gov

Motivation

DOE HEP builds and operates among the most difficult and biggest projects with the most complex devices in science -- accelerators and detectors. Our priority is using AI for real-time controls, operations, and data processing to **accelerate HEP science**.

Algorithms for HEP science

Computing hardware and infrastructure

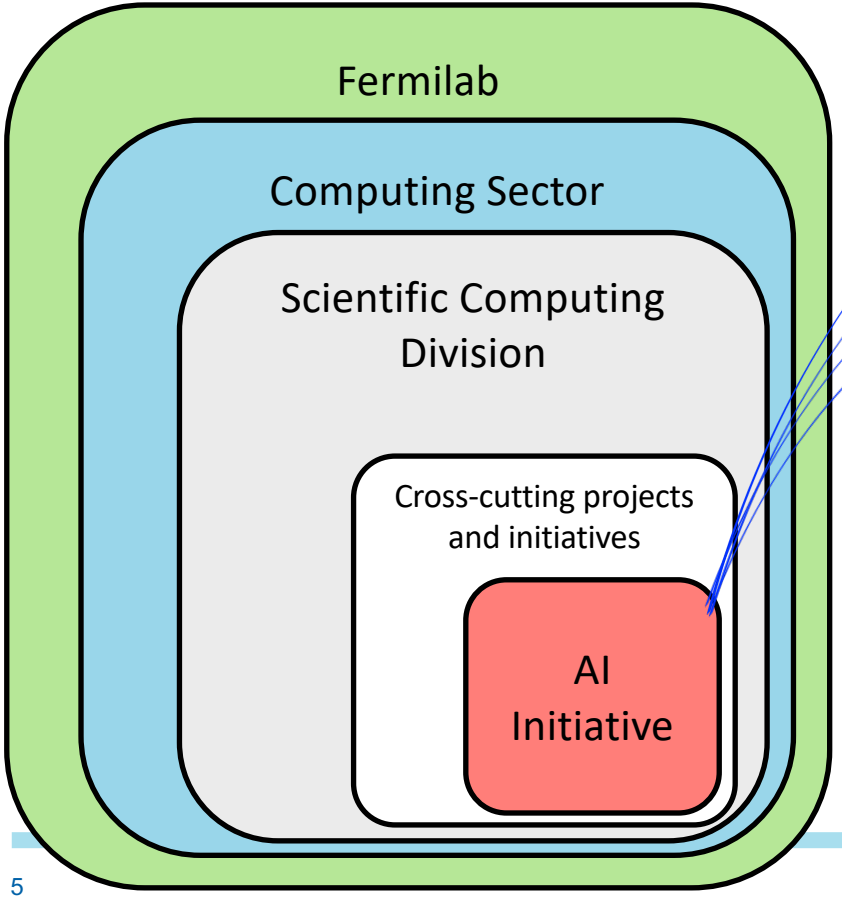
Operations and control systems

Real-time AI systems at edge

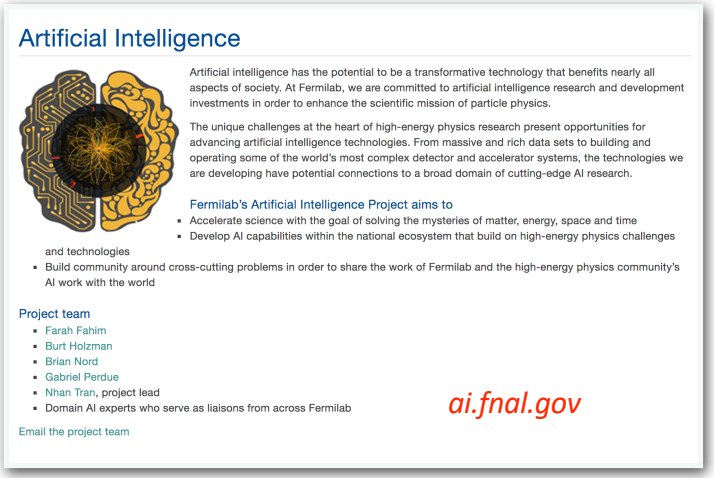
Mission

- Developing **strategic capabilities** within the (inter)national AI ecosystem
  - AI to advance lab scientific mission, and where Fermilab can advance AI research
- Building **community** around cross-cutting problems, tools, and educational opportunities
  - Connecting teams across the lab and keeping a big-picture view of what is going on
  - Develop infrastructure for AI research — both people (e.g. AI associate program) and hardware (e.g. GPU access)
- Establish a strategy to support a **strong funding profile** through network of stakeholders and partners
- **Sharing** Fermilab and HEP's AI work with the world

AI Program Office: How It Started



Lab-wide initiative
Formal home in SCD,
but engaging the entire laboratory



Artificial Intelligence

Artificial intelligence has the potential to be a transformative technology that benefits nearly all aspects of society. At Fermilab, we are committed to artificial intelligence research and development investments in order to enhance the scientific mission of particle physics.

The unique challenges at the heart of high-energy physics research present opportunities for advancing artificial intelligence technologies. From massive and rich data sets to building and operating some of the world's most complex detector and accelerator systems, the technologies we are developing have potential connections to a broad domain of cutting-edge AI research.

Fermilab's Artificial Intelligence Project aims to

- Accelerate science with the goal of solving the mysteries of matter, energy, space and time
- Develop AI capabilities within the national ecosystem that build on high-energy physics challenges and technologies
- Build community around cross-cutting problems in order to share the work of Fermilab and the high-energy physics community's AI work with the world

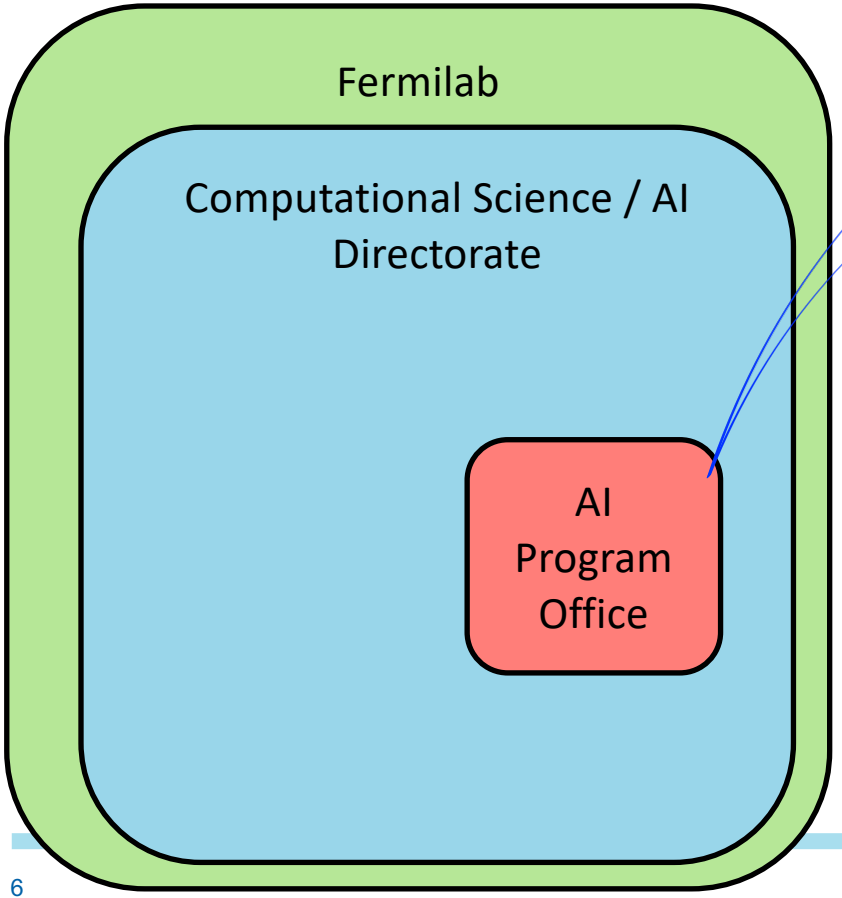
Project team

- Farah Fahim
- Burt Holzman
- Brian Nord
- Gabriel Perdue
- Nhan Tran, project lead
- Domain AI experts who serve as liaisons from across Fermilab

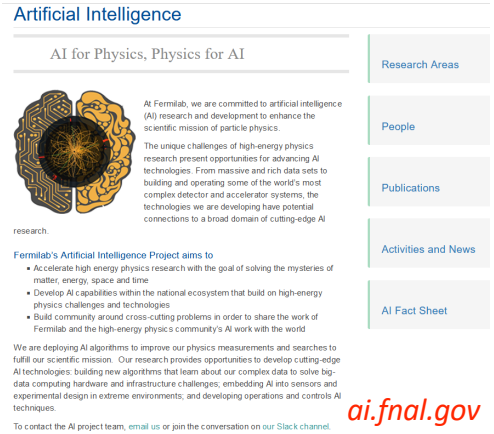
Email the project team

ai.fnal.gov

AI Program Office: How It's Going



Lab-wide initiative
Key to the CS/AI Directorate


Artificial Intelligence

AI for Physics, Physics for AI

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Fermilab's Artificial Intelligence Project aims to

- Accelerate high energy physics research with the goal of solving the mysteries of matter, energy, space and time
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- Build community around cross-cutting problems in order to share the work of Fermilab and the high-energy physics community's AI work with the world

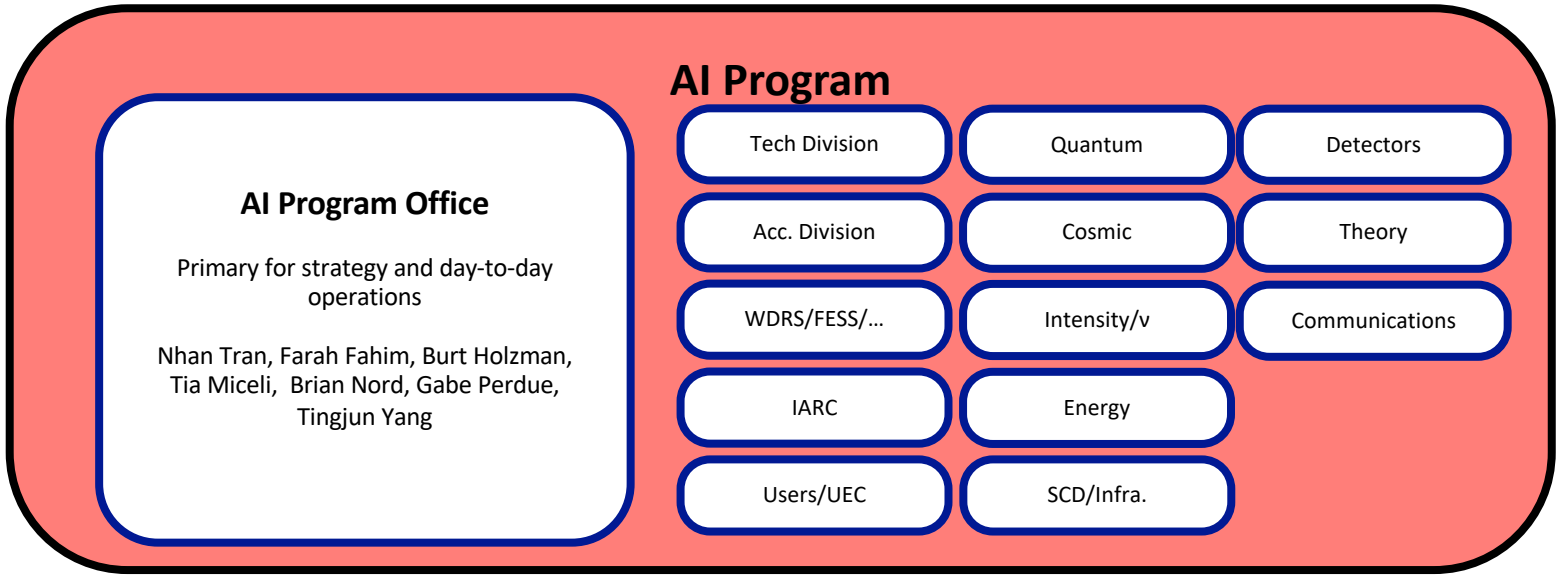
We are deploying AI algorithms to improve our physics measurements and searches to fulfill our scientific mission. Our research provides opportunities to develop cutting-edge AI technologies: building new algorithms that learn about our complex data to solve big-data computing hardware and infrastructure challenges; embedding AI into sensors and experimental design in extreme environments; and developing operations and controls AI techniques.

To contact the AI project team, email us or join the conversation on our Slack channel.

Research Areas
People
Publications
Activities and News
AI Fact Sheet

ai.fnal.gov

AI Program and Liaisons



Liaisons: link across the laboratory

communicate interests and needs of focus area to AI project and focus area participants
providing input to overall AI project strategy
organize materials, inputs for AI-related funding calls and communications.

Current AI Liaisons

- Accelerators: Aisha Ibrahim, Jason St. John
- Cosmology: Aleksandra Ćiprijanović
- Detectors: Ryan Rivera
- IARC: Charles Thangaraj
- LHC: Lindsey Gray, Kevin Pedro
- Neutrinos: Giuseppe Cerati, Marco Del Tutto
- Quantum: Jim Kowalkowski
- Theory: Stefan Hoeche, Josh Isaacson

NB: this list is rather old (pre-pandemic)

AI Liaisons - Responsibilities

- Monthly meetings with AI Program Office (fallen by the wayside but will restart soon!)
- Let their areas know what's happening with AI
- Let the AIPO know what's happening in their areas
- Ask questions / give feedback / think creatively!

- Let us know if you want to be an AI Liaison

How we can help support you

- Computing/Resources
  - Elastic Analysis Facility: https://analytics-hub.fnal.gov
  - Wilson/Institutional Cluster: https://computing.fnal.gov/wilsoncluster
- Advice/education
  - Seminar series, Tutorials
  - Lab-wide AI meeting
- Community Building
  - Workforce development
  - Future AI Jamboree
  - Engage broader AI & HEP community
  - Foster existing and growing collaborations with laboratories, universities, industry

What else do we do?

- Coordinating responses to Funding Opportunity Announcements for AI
  - Requires a great deal of strategic and tactical planning
  - Align proposals with laboratory strengths
  - Understand when we should lead multi-institution proposals vs. when to be a strong partner
- Meet regularly with CSAID and Laboratory senior management
  - Coordination with high-level lab and agency strategy
  - Check priorities and time/resource allocation

Sharing Fermilab and HEP's AI Work

Fermi National Accelerator Laboratory September 2020

Artificial intelligence research at Fermilab

Artificial intelligence research at Fermilab plays an important role in every aspect of high-energy physics: in the operation of particle accelerators, the analysis of data captured by particle detectors, sweeping surveys of stars and galaxies, quantum simulations of physical phenomena.

Fermilab is using cutting-edge AI algorithms and hardware implementations to work with large and complex data sets produced by big experiments such as the Deep Underground Neutrino Experiment, CMS and the Dark Energy Survey. Photo: Reidar Hahn, Fermilab

AI for physics, physics for AI

The unique challenges of high-energy physics research present opportunities for advancing AI technologies. From the principles of fundamental physics underlying massive and rich data sets to building and operating some of the world's most complex detector and accelerator systems, the technologies we are developing have potential connections to a broad domain of cutting-edge AI research.

Fermilab is committed to artificial intelligence research and development to enhance the scientific mission of particle physics:

- Accelerate science with the goal of solving the mysteries of matter, energy, space and time.
- Develop AI capabilities within the national ecosystem that build on high-energy physics challenges and technologies, including training the next generation of AI researchers.
- Build community around cross-cutting problems in order to share the work of Fermilab and the high-energy physics community with the world.

AI will enable more efficient operations at the Fermilab Linear Accelerator. Photo: Reidar Hahn, Fermilab

Accelerator physics

Fermilab builds and operates high-energy, high-intensity particle accelerators. The lab's strict demands for safety and scientific rigor drive innovation in machine learning. The accelerators are a prime test bed for a diverse suite of possible machine learning applications, such as reinforcement and online learning, efficient data collection, and automated control systems.

Modern detectors require ultrafast and powerful AI for data processing embedded into sensor electronics.

Smart detectors, accelerated compute, and real-time AI

Increasingly complex science applications are exponentially raising demands on underlying detector systems to optimize data flow. To enable real-time performance, detectors need to be faster, efficient, and more proactive, identifying and responding to bottlenecks before they become significant. To achieve this, Fermilab is developing and co-designing state-of-the-art AI chips, circuits, and coprocessors for fast inference and more efficient use of AI algorithms.

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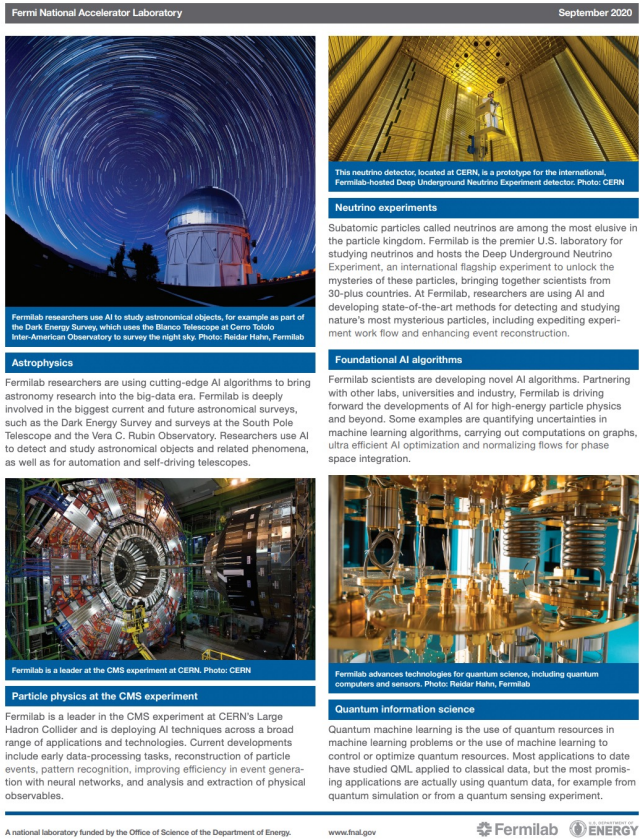

Fermi National Accelerator Laboratory September 2020

Fermilab researchers use AI to study astronomical objects, for example as part of the Dark Energy Survey, which uses the Blanco Telescope at Cerro Tololo Inter-American Observatory to survey the night sky. Photo: Reidar Hahn, Fermilab

Astrophysics

Fermilab researchers are using cutting-edge AI algorithms to bring astronomy research into the big-data era. Fermilab is deeply involved in the biggest current and future astronomical surveys, such as the Dark Energy Survey and surveys at the South Pole Telescope and the Vera C. Rubin Observatory. Researchers use AI to detect and study astronomical objects and related phenomena, as well as for automation and self-driving telescopes.

Fermilab is a leader at the CMS experiment at CERN. Photo: CERN

Particle physics at the CMS experiment

Fermilab is a leader in the CMS experiment at CERN's Large Hadron Collider and is deploying AI techniques across a broad range of applications and technologies. Current developments include early data-processing tasks, reconstruction of particle events, pattern recognition, improving efficiency in event generation with neural networks, and analysis and extraction of physical observables.

This neutrino detector, located at CERN, is a prototype for the international, Fermilab-hosted Deep Underground Neutrino Experiment detector. Photo: CERN

Neutrino experiments

Subatomic particles called neutrinos are among the most elusive in the particle kingdom. Fermilab is the premier U.S. laboratory for studying neutrinos and hosts the Deep Underground Neutrino Experiment, an international flagship experiment to unlock the mysteries of these particles, bringing together scientists from 30-plus countries. At Fermilab, researchers are using AI and developing state-of-the-art methods for detecting and studying nature's most mysterious particles, including expediting experiment work flow and enhancing event reconstruction.

Foundational AI algorithms

Fermilab scientists are developing novel AI algorithms. Partnering with other labs, universities and industry, Fermilab is driving forward the developments of AI for high-energy particle physics and beyond. Some examples are quantifying uncertainties in machine learning algorithms, carrying out computations on graphs, ultra efficient AI optimization and normalizing flows for phase space integration.

Fermilab advances technologies for quantum science, including quantum computers and sensors. Photo: Reidar Hahn, Fermilab

Quantum information science

Quantum machine learning is the use of quantum resources in machine learning problems or the use of machine learning to control or optimize quantum resources. Most applications to date have studied QML applied to classical data, but the most promising applications are actually using quantum data, for example from quantum simulation or from a quantum sensing experiment.

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AI Fact Sheets put together by

Aleks Ćiprijanović
Diana Kafkes

https://news.fnal.gov/wp-content/uploads/artificial-intelligence.pdf

Looking ahead

- We expect more support for AI research from the DOE and other places to be on the horizon
- We will respond to DOE Funding Opportunity Announcements programs, possibly applying to be an AI Center
- Collaborations with:
  - UChicago and Argonne (e.g. JTFI (in the past))
  - Schmidt Fellows (https://news.uchicago.edu/story/new-schmidt-futures-fellowship-uchicago-foster-next-generation-ai-driven-scientists)
  - DPI (https://dpi.uillinois.edu/)
- SBIR FOA coming in 2 weeks
- LDRD (next year)

C56-39. ARTIFICIAL INTELLIGENCE/MACHINE LEARNING FOR ACCELERATORS .....
a. Machine Learning, Diagnostics, Controls and Digital Twins for Particle Accelerators ..
b. Adaptive Online Machine Learning for Dynamic Beam Diagnostics .....
c. Other .....

Mind map of AI topics

Inverse problem for nuclear modeling/tuning

Normalizing flows for accelerating MCs

Fast ML Geant/Detector simulation

Domain adaptation for robust learning (data/MC, faults,…)

Simulation based-inference

Predictive maintenance from big data

Optimization algorithms for improved accelerator tuning

Improved reconstruction and analysis sensitivity

Algorithms for HEP science

Uncertainty quantification and fault tolerance

Operations and control systems

Geometric deep learning for HEP data representations

Physics-constrained ML; inductive bias

Distributed real-time control systems

Self-driving, reinforcement learning systems for control and operations

Anomaly detection and monitoring

Real-time embedded system AI; unique engagement w/industry and other SC domains

Computationally efficient model training and implementation

Real-time AI systems at edge

Computing hardware and infrastructure

AI analysis facilities supporting multiple ML workflows

AI-on-chip: 1st detector ASIC; novel microelectronics on-sensor AI

Open-source tool flows and AI democratization; FAIR ML data and benchmarking

Integrating novel heterogeneous computing platforms for high throughput HEP workflows